SECTION II.—GENERAL METEOROLOGY.

SOLAR DISTURBANCES AND TERRESTRIAL WEATHER.

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[Dated: Yale University, New Haven, Conn., Mar. 7, 1918.]

(*Continued from* this REVIEW, April, 1918, p. 177.)

III. FACULÆ AND THE SOLAR CONSTANT COMPARED WITH BAROMETRIC GRADIENTS.

Faculæ and barometric gradients.

As evidences of the sun's activity, faculæ and the solar constant are presumably no less important than sunspots. Therefore before drawing any final conclusions we may well study their terrestrial relationships in the same way that we have studied those of sunspots. Unfortunately faculæ are visible only near the margins of the sun's disk. Hence, although they are measured as carefully as the spots, the data are far less complete. We can, however, apply to them the method of quadrant differences used in the previous chapters of this memoir, since that method deals with the sun's marginal portions. Table 12 and figure 15 illustrate what happens when there is a marked quadrant difference in the faculæ; that is, when the area of the faculæ in the northwest plus the southeast quadrants of the sun greatly exceeds the area in the northeast plus the southwest quadrants. In figure 15 the dotted line at the top shows the average daily change in barometric gradients in the northern section of the North Atlantic Ocean in respect to 34 days in 1907 when the solar faculæ showed maximum quadrant differences. The solid line has been added for comparison. It illustrates the same conditions in respect to 34 days showing maximum quadrant differences in the *umbræ*. The umbral line shows a marked maximum during the time of solar disturbance. The facular line does the same, but to a less degree. In general the facular line seems to be shifted one or two days to the left of the other. It is impossible to tell whether the faculæ really produce a terrestrial effect or whether they appear to do so because their area varies roughly in harmony with that of the spots.

The remaining lines of figure 15 represent the barometric variability during 1910–1913 in the northern section of the North Atlantic before and after periods of strong quadrant differences in the faculæ, and the average for both sections of the Atlantic for the five years 1907, 1910, 1911, 1912, and 1913. These lines as a whole present little evidence of any solar relationship. In 1910, to be sure, when sunspots were fairly numerous, the line rises to a pronounced maximum at the end of the time when the quadrant differences of the faculæ were high. In this case, however, as in 1907, the effect may be due to the sunspots and not to the faculæ. In 1911–1913 when there were almost no sunspots, the faculæ were also reduced in numbers, but not to so great an extent as the sunspots. Therefore if their quadrant differences have any effect upon terrestrial weather we should expect some sign of it. Nothing of the kind, however, is apparent.

Instead of beginning with the sun, as is done in figure 15, let us begin with the earth. In figure 16, which is based on Table 13A, the dotted lines represent the facular quadrant differences before and after periods when the Atlantic Ocean suffered an especially severe barometric disturbance such that there was a marked flattening of the barometric gradients in the southern part of the North Atlantic almost coincident with a marked increase in the gradients of the northern section. These conditions are the same as those described in relation to figure 8 [p. 140]. The lines for 1907 and 1910 suggest a relationship between faculæ and storms. In these years, however, sunspots were fairly abundant and the apparent relationship of the faculæ may be due simply to their occurrence in conjunction with sunspots. The years 1911 to 1913, when faculæ were relatively more abundant than sunspots, although both were scanty, suggest no relationship of any kind between the sun and the earth. Hence whether we proceed from the earth to the sun or in the reverse direction it appears that so far as quadrant differ-.

TABLE 12.—*Changes in barometric gradients in percentages of normal in relation to days of largest differences between the areas of the faculæ in NW.+SE. quadrant and NE.+SW. quadrant (see fig. 15).*

	Quadrant differences.	Days before.								Disturbance.					Days after.							
		8	7	6	5	4	3	2	1	1	2	3	4	5	1	2	3	4	5	6	7	8
1907.																						
Cases	1,160	5	8	11	12	16	16	20	25	34	19	6	1	0	34	31	28	27	14	11	11	7
Average, northern section	....	15.6	25.5	14.0	16.1	18.8	12.8	15.6	16.7	20.0	23.1	20.3	12.0	0	17.2	19.1	13.8	13.6	19.1	14.7	18.5	12.4
Average, southern section	....	13.8	13.0	20.5	26.6	19.4	17.7	15.5	17.5	20.2	17.6	22.1	3.0	0	17.2	17.4	19.5	20.3	15.6	12.4	23.8	18.4
1910.																						
Cases	660	8	11	12	12	14	19	20	20	30	11	8	3	2	30	27	25	21	13	12	12	9
Average, northern section	....	17.7	15.6	12.7	13.6	15.8	13.9	13.9	16.3	18.4	13.6	15.2	11.0	19.5	20.8	17.7	17.8	13.8	13.9	11.2	13.0	17.2
Average, southern section	....	20.5	12.8	10.8	16.4	15.0	18.8	21.2	20.3	17.6	21.0	21.0	7.9	36.0	16.7	18.4	22.0	20.3	18.8	13.3	23.7	20.0
1911.																						
Cases	400	9	9	9	11	12	12	14	17	30	11	4	0	0	30	25	21	19	12	10	9	9
Average, northern section	....	16.2	19.8	12.8	11.4	16.7	16.4	19.4	14.2	14.5	17.7	7.5	0	0	16.0	16.7	15.6	17.5	16.7	16.8	22.1	13.3
Average, southern section	....	26.4	14.6	21.2	19.2	20.4	15.3	19.1	17.6	16.8	13.8	18.0	0	0	19.1	12.5	21.4	11.1	20.1	17.6	17.2	14.2
1912.																						
Cases	310	6	9	13	13	15	16	17	18	30	16	9	3	0	30	27	21	20	13	13	11	7
Average, northern section	....	17.2	14.2	11.9	16.0	20.0	15.3	19.6	18.5	18.0	8.8	14.3		......	14.8	19.2	20.4	16.6	15.3	23.9	14.0	14.1
Average, southern section	....	15.0	21.5	21.4	13.1	17.5	24.9	23.0	13.1	14.9	17.1	17.8		......	13.4	19.2	21.7	23.4	16.9	13.7	18.4	19.7
1913.																						
Cases	190	6	8	9	10	11	12	12	19	30	17	6	2	1	30	24	22	19	10	9	9	7
Average, northern section	....	22.0	19.9	20.2	14.0	18.4	18.4	18.0	21.6	21.9	20.2	14.7			15.8	16.8	19.3	19.3	16.4	15.4	24.0	13.4
Average, southern section	....	21.3	13.9	10.0	9.7	20.3	14.9	11.0	19.0	20.1	17.1	20.0			18.0	13.7	12.0	14.1	28.7	23.9	25.0	21.1

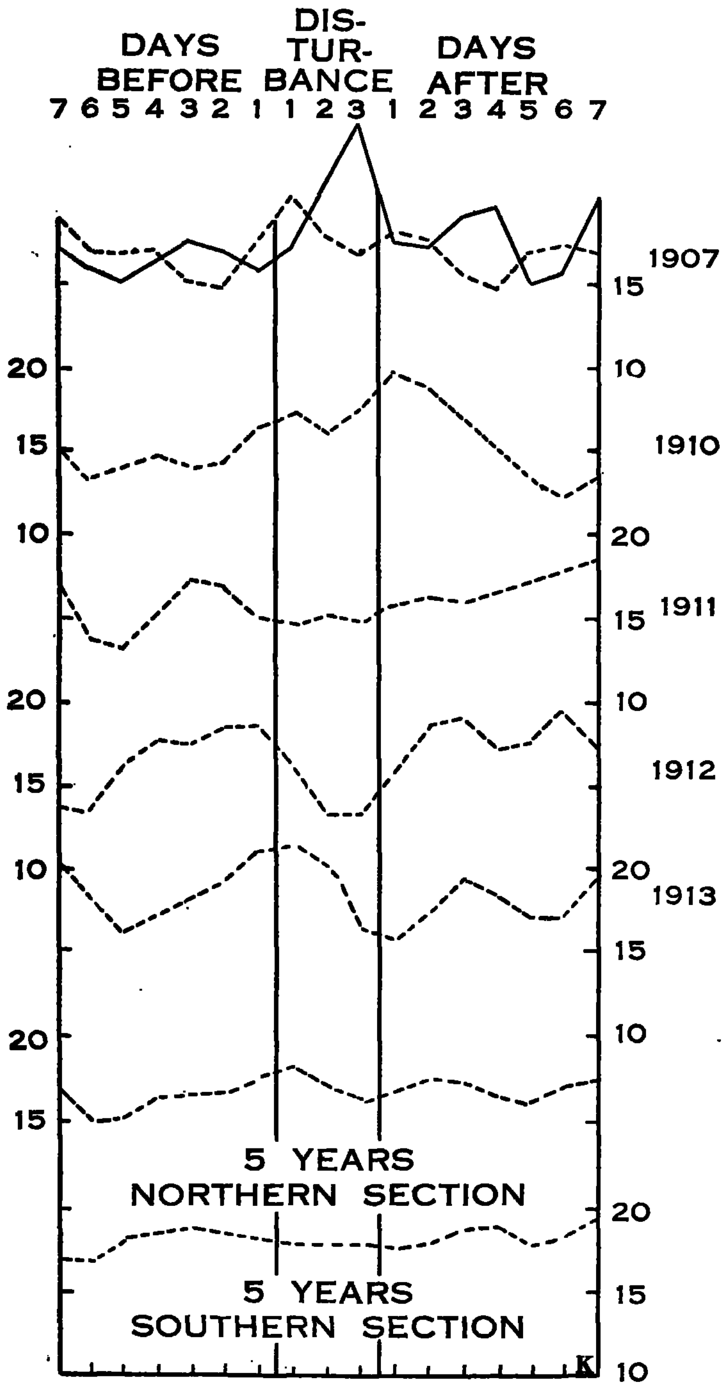

FIG. 15.—Changes of barometric gradients in relation to quadrant differences of faculæ. (See Table 12.)

ences are concerned faculæ probably are not important. They may have another type of relationship as we shal soon see, but that is a different question.

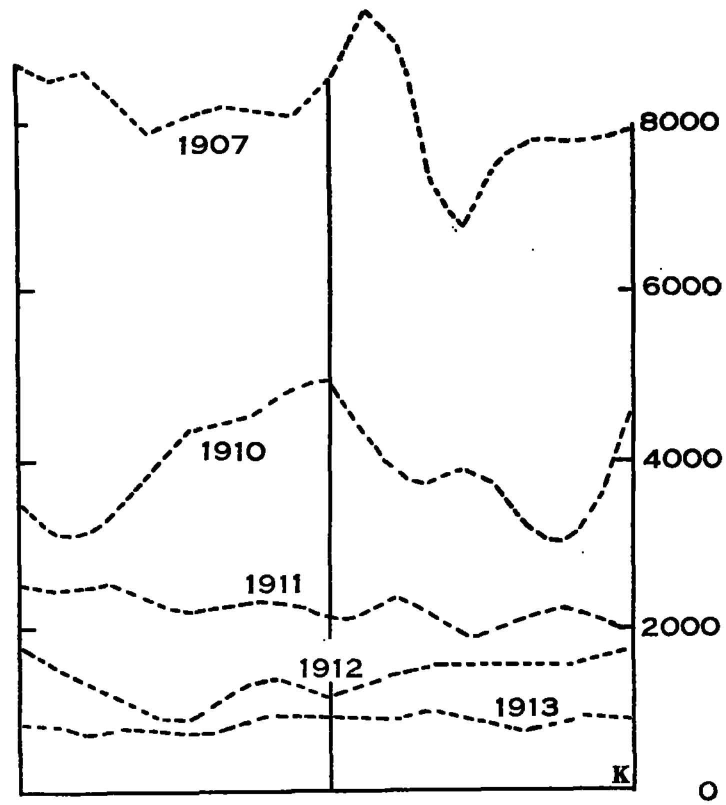

FIG. 16.—Quadrant differences of faculæ in relation to periods of special storminess in the Atlantic Ocean. (See Table 13-A.)

Comparisons between solar constants and barometric gradients.

Let us next compare the earth's changes of weather with the solar constant. This is done in Tables 14 and 15, and in figures 17 and 18. The method employed for figure 17 is almost the same as in the previous tables and diagrams, but differs a little because the figures for the solar constant are not available for every day nor for the whole year. For the years 1906, 1908, and 1909 I have selected all the days, 76 in number, having a solar constant of 1.950 or more, according to Abbet. For each of these days the change of gradients in the northern and southern sections of the North Atlantic Ocean has been tabulated and also the change on each of the 8 preceding and the 15 succeeding days. This method puts all the days with high constants into a single group, no matter whether they are the first or later days of a disturbed period. It also causes the gradients of some days to be tabulated twice, since they fall before one disturbance and after another. If the method were applied to line A in figure 10, for instance, it would cause the maximum to occur on the day corresponding to the zero of figure 16. The maximum would not be

TABLE 13A.—*Quadrant difference of faculæ in relation to periods of marked barometric disturbance in Atlantic Ocean involving either low gradient or a sudden decrease of gradients in southern part accompanied or closely followed by a great increase in strength of gradients in northern part (see fig. 16).*

Year.	Days preceding barometric disturbance.											Days following barometric disturbance.										Number of days.
	10	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	10	
1907	2,000	1,971	1,768	2,079	1,671	1,717	1,747	1,835	1,867	1,804	1,673	2,329	2,013	1,529	1,214	1,795	1,636	1,665	1,758	1,613	1,931	29
1910	877	934	686	850	775	959	1,188	985	1,210	1,145	1,366	998	996	927	1,019	942	819	603	1,025	1,242	1,092	26
1911	589	605	647	542	691	524	533	572	564	563	531	466	631	545	411	537	495	592	507	468	513	26
1912	380	555	272	323	308	217	154	315	363	269	307	275	403	351	368	381	402	354	418	459	357	21
1913	167	220	204	169	201	201	146	205	196	247	221	202	231	240	243	177	197	207	228	211	188	27
Sums	4,013	4,285	3,577	3,963	3,646	3,618	3,768	3,912	4,200	4,028	4,098	4,270	4,274	3,592	3,255	3,832	3,549	3,421	3,936	3,993	4,111	129

TABLE 13B.—*Total areas of faculæ in relation to periods of marked barometric disturbances in Atlantic Ocean involving either low gradients or a sudden decrease of gradients in southern part accompanied or closely followed by a great increase in strength of gradients in northern part.*

NOTE.—This table is not illustrated by a diagram because it adds no new idea. In general it confirms the idea that faculæ as well as sunspots—but to a less marked degree—are usually numerous at about the time when barometric disturbances are especially marked.

Year.	Days preceding barometric disturbance.											Days following barometric disturbance.										Number of days.
	10	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	10	
1907	5,479	5,674	5,428	5,640	5,524	5,149	5,610	5,444	5,683	5,586	5,849	5,791	5,525	4,995	5,048	5,610	5,828	5,833	5,424	5,440	5,734	29
1910	2,461	2,230	2,256	2,664	2,515	2,433	2,521	2,410	2,704	2,719	2,744	2,619	2,699	2,920	2,781	2,532	2,512	2,364	2,725	2,760	2,590	26
1911	966	1,040	1,096	1,146	1,061	1,019	1,031	995	1,117	1,089	1,145	1,076	1,057	1,053	987	1,022	948	1,106	1,095	1,174	1,083	26
1912	450	596	450	501	361	280	253	339	450	363	334	371	499	437	511	523	574	559	561	534	584	21
1913	206	271	240	212	211	227	167	231	217	247	236	314	230	210	221	242	273	235	276	221	257	27
Sums	9,562	9,811	9,470	10,163	9,672	9,108	9,582	9,419	10,171	10,004	10,308	10,201	10,010	9,645	9,548	9,929	10,135	10,097	10,084	10,129	10,248	129

TABLE 14.—*Changes in barometric gradients in relation to days having a solar constant of 1.950 or more (see fig. 17).*

Year.	Northern section of North Atlantic.																							
	Days before high solar constant.									Days after high solar constant.														
	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1906	409	433	317	470	267	333	377	389	389	443	456	423	433	426	457	401	421	405	389	461	471	409	382	418
1908	655	674	632	441	594	506	472	500	485	523	602	457	597	448	588	539	585	696	688	544	504	553	566	663
1909	281	231	289	275	305	330	296	318	194	208	234	330	253	193	313	313	334	251	185	251	288	281	311	227
Total	1,345	1,338	1,238	1,186	1,166	1,169	1,145	1,207	1,068	1,174	1,292	1,210	1,283	1,067	1,358	1,253	1,340	1,352	1,262	1,256	1,263	1,243	1,259	1,308
Mean=Total÷76	17.7	17.6	16.3	15.6	15.3	15.4	15.1	15.9	14.1	15.4	17.0	15.9	16.9	14.1	17.9	16.5	17.6	17.8	16.6	16.5	16.6	16.3	16.5	17.2

Year.	Southern section of North Atlantic.																							
	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1906	423	502	426	435	592	583	359	517	475	488	485	664	478	441	513	615	517	525	608	536	301	449	576	461
1908	709	639	665	605	599	590	659	555	573	632	574	556	653	704	509	586	593	621	611	617	715	762	502	634
1909	371	286	263	225	268	383	238	277	332	374	294	301	257	305	328	356	313	311	219	243	353	401	328	338
Total	1,503	1,427	1,354	1,265	1,459	1,556	1,256	1,349	1,380	1,494	1,253	1,521	1,388	1,450	1,350	1,557	1,423	1,457	1,438	1,396	1,369	1,612	1,406	1,433
Mean=Total÷76	19.8	18.8	17.8	16.7	19.2	20.5	16.5	17.7	18.2	19.7	16.5	20.0	18.3	19.1	17.8	20.5	18.7	19.2	18.9	18.4	18.0	21.2	18.5	18.9

TABLE 15.—*Departures of barometric gradients from normal in the North Atlantic Ocean in relation to days with high and low solar constants in the years 1906, 1908, and 1909 (see fig. 18).*

SOUTHERN SECTION.

Day	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*
High constants	.....	−0.7	−0.4	−0.6	−1.7	−2.2	−1.5	−0.2	0.0	+0.2	+0.7	+0.7	+0.5	+0.7	0.0	−0.9	−1.0	−1.4	−1.7	−0.7	+0.6	+1.0	+0.3	−0.8	−1.0
Low constants	.....	+0.3	+0.3	−0.2	−0.1	+0.6	+0.7	+0.1	−0.8	−1.0	−0.7	−0.4	−0.1	+0.2	−0.1	−0.1	+0.2	+0.5	0.0	−0.4	−0.5	+0.1	+0.5	+1.0	+1.0
Day	*25*	*26*	*27*	*28*	*29*	*30*	*31*	*32*	*33*	*34*	*35*	*36*	*37*	*38*	*39*	*40*	*41*	*42*	*43*	*44*	*45*	*46*	*47*	*48*	*49*
High constants	−0.5	+0.1	+0.4	+0.4	−0.3	−0.9	+0.4	0.0	+0.1	+0.5	+1.1	+1.1	+1.0	+1.3	+1.2	+0.4	+0.3	+0.5	+0.4	+0.8	+1.6	+1.9	+1.6	+1.6	+1.5
Low constants	+1.0	+0.6	−0.3	−0.6	−0.5	+0.4	+1.6	+2.0	+1.3	+1.1	+1.1	+0.9	+1.1	+1.2	+1.2	+1.6	+1.6	+1.0	+0.7	+0.8	+0.9	+0.6	−0.1	−0.3	−0.6

NORTHERN SECTION.

Day	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*
High constants	.....	−2.6	−2.3	−1.7	−0.1	+0.7	+0.6	+1.4	+2.1	+1.7	+0.7	−0.6	−0.8	+0.4	+0.4	+0.2	−0.1	−0.1	+0.5	−0.3	−2.0	−2.2	−2.1	−1.4	−0.6
Low constants	.....	+2.5	+1.8	+1.3	+0.3	+0.5	+0.6	−0.3	−1.2	−2.1	−2.6	−1.5	−0.7	−0.9	−0.6	+0.3	+0.8	+0.2	+0.9	+0.4	+0.3	−0.7	−1.5	−1.1	+0.3
Day	*25*	*26*	*27*	*28*	*29*	*30*	*31*	*32*	*33*	*34*	*35*	*36*	*37*	*38*	*39*	*40*	*41*	*42*	*43*	*44*	*45*	*46*	*47*	*48*	*49*
High constants	−0.7	−1.0	−0.6	−0.7	−0.7	−0.4	−0.3	−0.1	+0.7	+1.0	+0.4	+0.3	+0.8	+0.7	+0.2	+0.3	+1.8	+2.9	+2.0	+0.6	+1.2	+2.3	+2.2	+1.6	+1.1
Low constants	+1.2	0.0	−1.4	−1.1	+0.3	+1.2	+0.5	−1.2	−1.3	−0.7	−1.2	−1.6	−0.2	+1.3	+1.4	+0.8	+0.5	+0.6	+0.8	+1.2	+1.0	+0.4	+0.1	0.0	−0.3

so high as now and the decline on either side would be more gentle. Nevertheless, the evidence of relationship between the sun and the earth would be as unmistakable as now and there would appear to be an immediate terrestrial response to solar changes.

According to the method here used a good many days of high constants are tabulated among the days preceding and following high constants. They tend to minimize whatever relationship may exist, but do not wholly obscure it. All the days of reference are characterized by high constants, whereas among the other days a smaller number is thus characterized as the interval before or after the day of reference increases.

In figure 17 the solar constant as thus tabulated seems to show a possible relation to terrestrial weather. The relation is, however, quite different from that of sunspots.

Provided they are smoothed, the lines for both the northern section of the North Atlantic, A, and the southern section, B, are at a minimum either on the day of the highest solar constant or the day before. From that time onward they rise irregularly for 8 or 9 days. Line C, showing the average for both sections of the North Atlantic, begins to

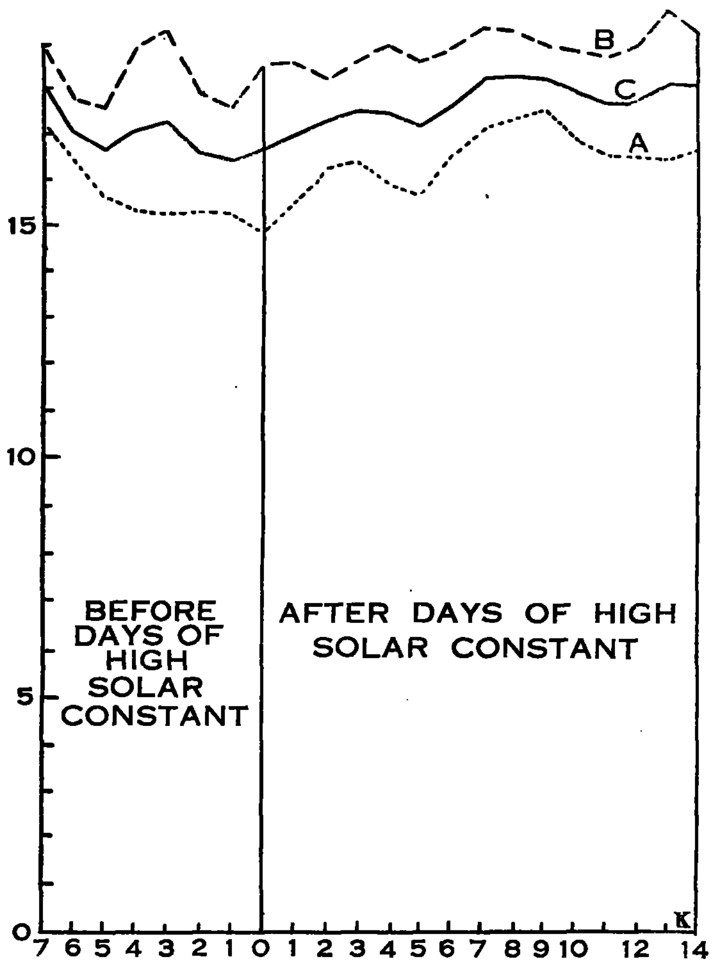

FIG. 17.—Changes in barometric gradients in the North Atlantic in relation to 76 days with solar constants of 1.950 or more, in 1906, 1908, and 1909. (See Table 14.) *B*, Southern section; *C*, both sections; *A*, Northern section.

rise on the day when the solar constant becomes high. If it were possible to obtain more complete figures of the solar constant, the line would doubtless smooth itself out. Just where the line would reach a maximum is not evident, perhaps on the 8th day after the high constant, but possibly not till later. However this may be, the general conclusion is clear. High solar constants during the years in question were followed by a slow but steady increase in the strength of the barometric gradients. The effect is apparently the same as that of an increase in the number of sunspots except that it acts more slowly. We may perhaps compare the temperature effect to the slow gentle rise of the tide, while the sunspot effect is like the shorter and more violent waves raised by the wind.

The relation of the solar constant to barometric gradients is illustrated in a slightly different way in Table 15 and figure 18. In preparing these the days for which solar constant observations are available in 1906, 1908, and 1909 were divided into three approximately equal groups for each year on the basis of the solar constant. The groups with the highest and lowest constants, respectively, were used as the basis for tabulating the departures of the barometric gradients from the normal in both sections of the North Atlantic for a period of 50 days after the days of high or low constants. The smoothed results appear in the upper four lines of figure 18. In the lower part of the figure the two sections have been combined. The lines for high and low constants are here referred to different zeroes in order that they may stand out clearly. In general both sections show the same features, but these are much stronger in the north than in the south. From the lower solid line, E, it is clear that *after days of high constants there is a steady increase in the variability of the weather in the North Atlantic. This culminates in 8 or 9 days, after which there is a slow decline. Low constants, F, on the contrary, are followed by a decrease in the variability of the weather. This culminates in 9 or 10 days.*

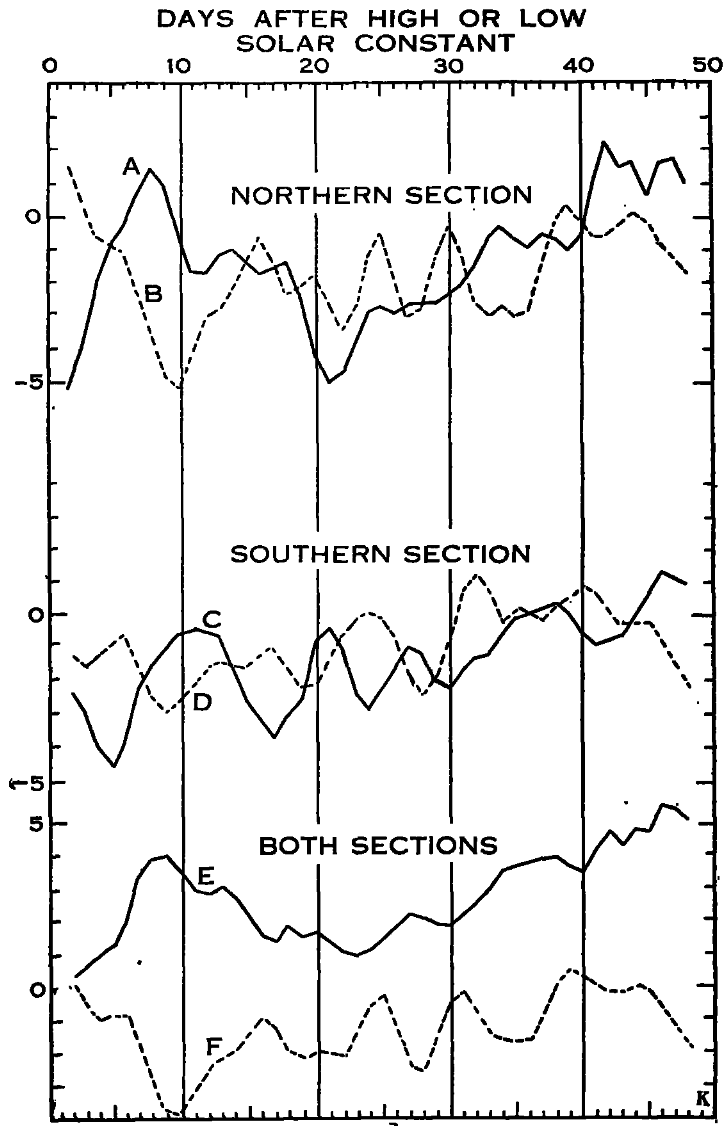

FIG. 18.—Departures of barometric gradients from normal in the Atlantic Ocean after days of high solar constants and low solar constants, 1906, 1908, 1909. ...... low solar constants. ——— high solar constants. (See Table 15.)

Both curves in the lower part of figure 18, but especially the one for high constants, show an upward tendency in their right-hand portions. Much if not all of this is due to the fact that this particular diagram represents an early stage in the present investigation. It is based on the actual indices for barometric gradients as obtained by counting intersections of isobars with the degree net. The numbers thus obtained were not reduced to percentages of the normal. From midsummer onward, which happens to be the period when most of the solar constant observations are made, the gradients increase in steepness. Therefore during a period of 50 days the amount of change from day to day is bound to increase because of the increasing severity of the season. Hence for our present purpose the general rise of the lines in figure 18 has no significance. The sudden initial rise of the solid lines and fall of the dotted ones, however, are highly important. They indicate an important relationship between the sun's thermal radiation and terrestrial atmospheric disturbances.

Relation of faculæ to the solar constant.

Let us now turn back to the faculæ once more. They are generally agreed to be hotter than the sun's general surface. Hence, they would be expected to produce an effect similar to that of the solar constant. When they first appear on the sun's margin, however, their effect would be slight, just as the effect of the rising sun is slight. If the faculæ retain their heat sufficiently long, as they probably do, they would send the maximum supply of heat to the earth 6 or 7 days after their first appearance; that is, when they are near the sun's center. Thus at that time they would cause a high solar constant. We have seen that high gradients occur about 9 days after high constants. Therefore 9 days after abundant faculæ reach the central meridian and about 16 days after they are visible on the sun's eastern margin we should look for high gradients. Table 16 and figure 19 show that this is almost what occurs. The table and diagram are based on the year 1907, which had abundant sunspots, and 1910–1913, which had few. The method of tabulation is like that already described; that is, after each period of abundant faculæ only those days are included which occur before another period of abundant faculæ arrives to confuse matters. Unfortunately the number of periods for which the full quota of days is available is small, as appears in the table. For the entire North Atlantic, as appears in figure 19, the gradients reach a slight maximum 5 days after the faculæ have become abundant on the eastern edge; that is, when they are close to the central meridian.

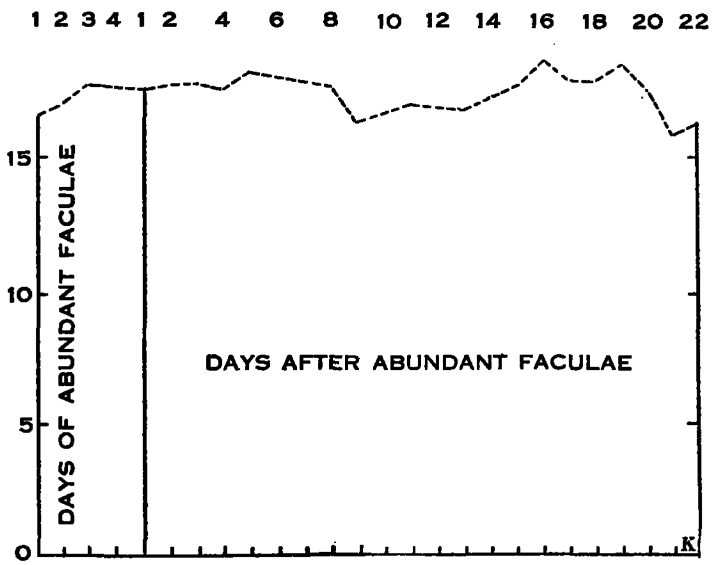

FIG. 19.—Changes in barometric gradients in northern section of the North Atlantic, in relation to faculæ on the sun's eastern margin. (See Table 16.)

A stronger but relatively slight maximum appears on the sixteenth and nineteenth days. This is quite closely in accord with what would be expected theoretically. Since it is preceded by a minimum on the ninth day, however, its importance is probably not great. So far as any conclusion is possible, we may say that the faculæ tend to show a delayed and inconclusive relationship to terrestrial

TABLE 16.—*Changes in barometric gradients in relation to days when the total area of faculæ on the sun's eastern margin amounts to 150 or more (see fig. 19).*

	Days of abundant faculæ.				Days after abundant faculæ.																							
	1	2	3	4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1907.																												
Number of cases	37	14	6	3	36	29	23	22	19	17	16	13	12	11	11	10	9	7	7	5	5	4	3	3	.....	.....	.....	.....
Average change in northern section	17.2	21.0	13.0	34.3	18.7	20.8	12.6	23.5	15.1	14.3	17.0	20.2	15.8	14.6	18.4	15.4	16.8	18.0	9.7	33.2	14.8	13.0	10.3	4.3	.....	.....	.....	.....
Average change in southern section	16.4	14.0	22.0	20.3	18.5	21.5	22.0	17.0	18.3	13.9	24.1	22.4	11.5	10.0	15.4	16.4	29.9	19.7	26.6	25.4	30.2	24.3	21.0	8.0	.....	.....	.....	.....
1910.																												
Number of cases	29	8	5	3	29	24	20	18	15	14	13	13	13	12	12	12	10	8	8	7	7	6	6	6	5	5	5	3
Average change in northern section	18.7	9.0	23.2	32.3	14.5	21.1	13.1	18.1	13.5	16.6	14.4	17.5	15.9	14.0	17.7	16.3	16.1	10.5	16.0	13.0	19.2	11.2	20.0	10.0	18.6	14.0	11.4	17.3
Average change in southern section	16.7	30.1	17.2	24.0	18.7	22.4	23.0	16.9	16.2	23.2	16.6	23.8	16.4	20.0	18.3	16.0	14.6	11.2	11.5	19.0	11.3	26.6	23.2	31.0	16.4	18.0	20.6	12.3
1911.																												
Number of cases	27	11	8	8	27	24	21	16	15	15	14	14	13	11	11	10	10	9	9	7	6	5	5	4	.....	.....	.....	.....
Average change in northern section	19.4	10.2	19.1	19.1	15.8	18.1	16.1	17.4	18.2	11.8	18.9	13.3	27.4	20.8	18.5	17.6	15.3	22.4	28.6	20.4	19.3	19.8	33.2	15.0	.....	.....	.....	.....
Average change in southern section	11.7	24.9	13.4	12.6	13.1	11.3	12.8	16.6	18.9	14.7	14.8	16.0	12.5	17.6	17.4	12.2	11.2	15.6	17.4	23.6	12.0	16.0	18.4	13.8	.....	.....	.....	.....
1912.																												
Number of cases	27	13	7	6	27	24	23	23	23	21	10	18	18	16	13	12	9	9	8	6	6	6	6	6	6	5	5	4
Average change in northern section	18.6	10.2	14.3	19.8	17.2	17.0	17.1	13.6	16.7	22.8	11.7	15.3	15.2	18.7	25.2	13.2	19.2	16.4	13.6	18.2	20.7	17.7	13.8	15.3	18.5	11.0	13.0	17.8
Average change in southern section	16.9	11.5	21.5	13.5	15.5	21.7	21.1	23.4	20.8	17.3	18.7	19.9	22.6	12.9	18.2	16.6	22.8	19.9	16.9	13.7	7.8	23.8	20.1	21.6	9.0	23.0	13.6	20.8
1913.																												
Number of cases	28	10	4	5	28	24	21	21	19	18	18	17	16	14	13	12	8	7	7	6	6	6	2	2	2	2	2	2
Average change in northern section	21.3	15.0	24.3	20.6	16.5	15.6	17.3	14.8	19.1	19.8	20.1	17.1	13.9	14.5	18.3	18.6	18.4	6.9	15.6	17.7	18.8	18.0	16.5	46.5	25.5	17.0	32.5	39.0
Average change in southern section	22.9	16.5	22.3	22.6	18.3	14.7	16.9	17.8	26.4	23.2	17.3	19.2	12.1	12.4	12.4	14.8	9.0	19.3	21.0	15.5	18.8	7.2	3.5	16.0	6.0	19.0	15.0	31.0

weather. This is probably thermal, and may be connected with the solar constant. It appears to be of a different type from the relationship which seems to connect sunspots and the weather.

IV. Correlation Coefficients.

Thus far, with the exception of figure 9 [p. 169], our investigations have been limited to periods when either solar activity or barometric gradients show extremes. Let us now try the method of correlation coefficients, which employs all the days no matter how much or how little they may depart from the normal. It must be clearly understood, however, that this method is primarily of value in cases where two phenomena are connected according to a systematic ratio such that when one is plotted as abscissas and the other as ordinates the resulting points form a straight line. There is no evidence that any such conditions confront us at present. Not only does the same solar cause produce *different* results in different types of pressure areas, but there is a *variable period of delay* between cause and effect, *several causes* are probably at work producing the same effect, and *the sunspots themselves are probably not a primary cause* but an indirect cause or else a result of some less obvious cause which also produces barometric disturbances. In fact, so many are the complicating factors that it will be highly significant if the use of correlation coefficients leads to any systematic confirmation of our conclusions, no matter how small.

Nevertheless, the method of correlation coefficients is so exact that it will be worth while to use it. First, however, the reader should recall the reasons why only the smallest coefficients can be expected even if solar variations are closely connected with barometric disturbances. Some of these reasons have already been stated in connection with a discussion of the conditions which prevent the earth's barometric variability from falling to a low ebb even when quadrant differences apparently cease to occur in the sun. The matter is so important, however, that it will pay to think of it once more.

In the first place, the method of correlation coefficients does not distinguish between the cyclonic and anticyclonic conditions which succeed one another at frequent intervals, even in regions of prevailing low pressure such as the northern section of the North Atlantic Ocean. The present investigation, like those of Hildebrandsson and others, seems to show that cyclonic and anticyclonic areas have an inverse relation to the sun. Hence when correlation coefficients are computed, the two types of barometric conditions tend to neutralize one another. Thus any coefficients which we may find represent only the amount by which one type of pressure prevails over the other.

In the second place, even at its point of origin, each new barometric disturbance is superposed upon the more or less vigorous remnants of previous disturbances. Some of these disturbances may have been associated with solar conditions which prevailed one or two weeks before. Moreover, a given disturbance can rarely be measured at its inception. According to the method employed in this paper, it may be measured only on its day of origin and may then disappear beyond the eastern side of the map, or it may be measured on its day of origin and for two to eight days afterwards as it crosses the map, or it may not be measured till several days after its origin, when at last it enters the area of the map. Any attempt to obviate this difficulty by selecting only the disturbances arising immediately from solar activity would involve the element of human judgment to such a degree that the results would be worthless. As the matter now stands, the element of human judgment in this particular phase of the problem is eliminated, although at the cost of greatly reducing the real coefficients.

A third reason why the method of correlation coefficients can not be expected to give striking results is the fact that barometric disturbances are due to many causes. Some of these are terrestrial. They include volcanic eruptions, forest fires, the heat sent out by great cities, periods of cloudiness, heavy rain, coatings of snow, and other meteorological accidents. Far more important than this is the great basic fact of meteorology, namely the variation in the amount of heat received on a given portion of the earth's surface because of changes in the sun's altitude both from hour to hour and from season to season. By reducing our barometric data to percentages of the daily normals we have largely eliminated the effect of the seasons, and have thus taken out the major correlation coefficient between the earth and the sun. It has been impossible, however, to eliminate the effect either of daily changes in the sun's altitude or of meteorological accidents or of minor occurrences like volcanoes. These all unite to conceal whatever correlation may actually exist between daily barometric gradients and daily solar disturbances.

Finally, the correlation between the atmosphere and the sun is reduced by solar conditions perhaps as much as by terrestrial. In the first place, we have no assurance that any one particular type of solar measurement gives a true measure of the energy available for the production of barometric disturbances. We have already seen that sunspots, the solar constant, and faculæ all seem to show some relationship to such disturbances. The relation of sunspots to terrestrial pressure seems to be immediate, whereas high solar constants are followed by high barometric gradients only after an interval of 8 or 10 days. Faculæ, on the other hand, seem to show both an immediate and a delayed relationship, but in a weakened indefinite form. Whatever may be the explanation of this apparently twofold relationship, it must blur the correlation coefficients. Moreover, the solar energy, no matter what its nature, must be transformed into kinetic energy before it can manifest itself in barometric pressure. In other words, heat or some other type of energy must be transformed into the kind of energy that moves the particles of air. Such a transformation causes delay and is almost inevitably accompanied by the wasting of energy. Hence it must cause still further reduction in the coefficients.

In view of these considerations we should not expect high correlation coefficients between solar changes and the earth's atmospheric pressure even though the relation is important. For example, with our present imperfect methods it would be a great mistake to expect the coefficients to be anything like so large as those which Clayton [1] has found between terrestrial temperature at inland tropical stations and the solar constant. The temperatures of the earth and the sun are so obviously in direct relation to one another that in this case we should expect a high correlation coefficient. Clayton finds that the average temperature of five-day periods at Pilar, in central Argentina, during the years 1913 and 1914 gives the following positive correlation coefficients when compared with the solar constant for five preceding days.

[1] Effect of short-period variations of solar radiation on the earth's atmosphere, by *H. Helm Clayton*. Smithsonian Institution, Washington, May, 1917.

TABLE 17.

(After Clayton, op. cit., p. 6.)

Days following solar observations....	0	1	2	3	4	5
(A) Correlation coefficient with maximum temperature............	+0.41	+0.52	+0.53	+0.48	+0.38	+0.25
(B) Correlation coefficient with mean temperature..................	+0.07	+0.27	+0.35	+0.35	+0.28	+0.14

As the probable error of the maximum in line A is only ±0.048, or less than one-eleventh of 0.53, the correlation seems to be so strong as to be beyond question. Clayton has confirmed this result by a similar study of stations in other parts of the world. Hence it seems fairly certain that changes in the sun's thermal radiation are soon followed by corresponding changes in the temperature of the lower layers of the atmosphere. The maximum effect occurs from one to three days after the solar cause.

In the case of so indirect and complicated a relationship as that between atmospheric pressure and solar changes we should expect the coefficients to be much smaller than in the case of temperature. For three tropical stations Clayton found that during 1913 the correlation between the solar constant and the pressure was negative for five days after the days of solar observation, but was too small to be significant, as appears in the first line of Table 18. In the other zones the coefficients are a little larger than within the Tropics and arrange themselves in the systematic order shown in the last two lines of Table 18. These coefficients are small, but in view of the complexity of the relationship and the regularity with which they arrange themselves they probably show a real relationship.

TABLE 18.

(After Clayton, op. cit. p. 10.)

Days following solar observations....	0	1	2	3	4	5
Correlation coefficient at 3 tropical stations..........	−0.05	−0.03	−0.04	−0.04	−0.01	−0.02
Correlation coefficient at 2 temperate stations..........	+0.09	+0.10	+0.12	+0.13	+0.13	+0.08
Correlation coefficient at 2 arctic stations..................	+0.12	+0.04	±0.00	−0.03	−0.07	−0.07

When the same method is applied to the correlation between the sun's quadrant differences for 1905 and the barometric gradients of the northern section of the North Atlantic, according to the formula $r=\frac{\Sigma xy}{\sqrt{\Sigma x^2 . y^2}}$, the results are as appear in Table 19.

In this formula r is the ratio, or correlation coefficient; x is the daily departure of the solar quadrant differences from the normal for the year; and y is the daily departure of the barometric gradients from the normal for the day in question, with due allowance for the seasons as explained in the early part of this paper (cf. pp. 125–126).

TABLE 19.

Days before or after solar observation.	Days before.				0	Days after.		
	4	3	2	1		1	2	3
Correlation coefficient..............	−0.075	−0.125	−0.128	−0.105	−0.054	+0.043	+0.092	+0.084

Probable error, ±0.05.

The figures in Table 19 are of the same order as those obtained by Clayton for his two stations in the Temperate Zone. They arrange themselves with great regularity. The maximum is found when a given solar condition is compared with the barometric gradients of the second day after.

A comparison of the solar constant with the *change* in gradients from day to day in the North Atlantic instead of with the actual gradients yields the result shown in Table 20.

TABLE 20.

Days before or after solar observation.	Days before.			0	Days after.			
	3	2	1		1	2	3	4
Correlation coefficient............	−0.029	±0.000	+0.054	+0.085	+0.125	+0.069	+0.065	+0.026

Probable error, ±0.05.

Here, as before, the coefficients arrange themselves with great regularity, rising to a maximum on the first day after the solar observations. This again agrees with our previous conclusions. It suggests that a given solar condition causes a change in the barometric gradients almost at once, so that this appears on the day in question and reaches a maximum on the succeeding day. On the second day after the day of solar observation the gradients are strong or weak in harmony with the preceding solar quadrant differences. Thus the conclusions drawn from correlation coefficients are entirely in accord with those drawn from other lines of evidence.

It might be supposed that a comparison of the barometric conditions with the solar condition during several preceding days would show a stronger relationship than when the comparison is limited to one day. This is not the case, however. When the quadrant differences for successive periods of four days during 1905 are compared with the barometric conditions of the last day in each period the correlation coefficient for the actual gradients is +0.099 and for the change of gradients +0.115. Here, however, as in the other cases, the correlation coefficients are consistent with our conclusions derived from other methods, which indicates that they are probably of real importance.

Another reason for believing that these correlation coefficients, though small, are of genuine significance is found when they are compared with the coefficients between faculæ and barometric gradients. The faculæ, like the sunspots, are reckoned in terms of quadrant differences, and the same days are used as in Table 19, above. The result, as shown in Table 21, is quite different.

TABLE 21.

Days before or after facular differences.	Days before.			0	Days after.			
	3	2	1		1	2	3	4
Correlation coefficient............	−0.024	−0.023	−0.018	+0.006	+0.006	−0.037	−0.0018	+0.002

Probable error, ±0.05.

Here the maximum coefficient is only one-fourth as large as in Tables 19 and 20. Moreover, the coefficients are not arranged systematically and are smaller than the probable error. Thus they confirm our previous conclusion that so far as any *immediate* effect upon barometric gradients is concerned the faculæ are relatively unimportant and probably owe their apparent effect to their nearness to the sunspots. The fact that in this case the absence of any evidence of a definite relationship is so clear gives reason to believe that the other coefficients obtained both by Clayton and in this paper are of real significance. Small as they are, they are larger than would be expected in view of the many complicating factors discussed on previous pages. Moreover, it must be carefully noted that each of the two sets of eight coefficients given in Tables 19 and 20, as well as each of the other two mentioned in the text, is *systematic*, and also completely in accord with the conclusions derived from other lines of investigation.

SUMMARY.

The net results of the study of solar and terrestrial relationships set forth in this paper and its predecessors may be summed as follows:

(1) Sunspots, faculæ, and the solar constant all appear to show a distinct relation to barometric gradients in the North Atlantic Ocean.

(2) The faculæ and the solar constant seem to show the same sort of relationships. They act entirely in harmony with the basal assumptions upon which the science of meteorology is founded. Their relation to the weather can be readily explained as the result of the varying amount of heat received upon the earth's surface from the sun. According to Clayton, the maximum heating effect in tropical regions is produced two or three days after the corresponding solar activity. According to the writer's figures the chief effect on barometric gradients in temperate latitudes does not appear until the eighth or ninth day. Thus the time relationships seem reasonable.

(3) The relation between sunspots and barometric gradients is not in harmony with the principles thus far accepted by meteorology. In the first place, although the effect of sunspots is apparently of the same order of magnitude as that of variations in the solar constant, it reaches its maximum with much greater speed. The apparent delay is less than 24 hours. This seems too quick to accord with the ordinary action of heat. In the second place, the effect of sunspots in high-pressure areas is apparently inverse to the effect in low. This seems to be contrary to what occurs when heat is the active agency, for the northern and southern sections of the North Atlantic Ocean appear to respond to the solar constant in nearly the same fashion. A much stronger piece of evidence is the fact that spots on different parts of the sun's surface do not appear to act at all as would be the case as if they emitted heat. The heat of the sun's surface must act most strongly on the earth when the heat radiates from the center of the sun's disk. This appears to be the case with the heat radiated by the faculæ. With sunspots the reverse is true. When they are at the sun's center they seem to check the formation of atmospheric disturbances upon the earth. When on the edges, however, where heat would have a minimum effect, they act most vigorously. Moreover, the spots upon the sun's margins do not produce an effect in proportion to their total area, as would be the case if they worked through the emission of heat. On the contrary, a spot on one part of the margin seems to balance a spot on certain other parts. Hence the greatest effects are produced either when what we have called the quadrant differences are at a maximum, or else when the area of the spots on the margin of one quadrant greatly overbalances the area in the other quadrants.

(4) In view of all these facts we seem to be led to the conclusion not only that variations in solar activity are among the prime causes of disturbances in the earth's atmosphere, but that these variations are of two kinds. One kind is clearly thermal. The other kind may be electrical or of some type not yet understood. The discussion of its nature is deferred to another paper.

Meanwhile a word should be added as to the present condition of the great problem of the cause of weather variations. With the appearance of Koppen's final work on sunspots and temperature in 1914 (1) it became almost certain that no further research could alter his original conclusion. That conclusion was that the earth is relatively warm at times when the sun is relatively inactive. This is especially the case in equatorial regions. At about the same time Abbot's measurements of the solar constant (2) made it highly probable that when the sun's surface is active the emission of heat is greater than when the number of sunspots is slight. Thus the meteorological world was face to face with the anomaly of a warm sun and a cool earth. The present author (3) has attempted to explain this by the hypothesis that at times of many sunspots an increase in cyclonic activity, which now seems to be well demonstrated, causes a great amount of warm air to be carried upward. There it dissipates its heat by radiation. This heat is apparently drawn from equatorial regions more than from others. This is partly because convection in the shape of thunderstorms and hurricanes seems to be especially active there during times of many sunspots. Moreover, in the belt of cyclonic storms most of the air that rises in the midst of the more frequent cyclones of periods with many sunspots is drawn from the equatorward side of the storms. Thus at times of many sunspots and a warm sun the earth's surface is most cooled in equatorial regions, less in temperate regions, and possibly not at all in polar regions. When this hypothesis was set forth in 1914 the chief difficulty seemed to be the necessity of postulating some agency other than heat in order to explain the increased cyclonic activity which is supposed to carry away the increased heat received from the sun.

After the present series of papers had been completed in practically the present form, there came to hand the admirable monograph of Helland-Hansen and Nansen. (4) In this they discuss changes in the temperature of the air and of the surface water of the North Atlantic in their relation to ocean currents and winds. With commendable thoroughness they show that, whatever may be the case with variations of long period, the short variations of temperature measured in months do not appear to be due to the movement of ocean currents. On the contrary, the variations occur suddenly over large areas instead of advancing progressively as would be the case if they were carried by the water. In places like Scandinavia it appears, moreover, that changes in barometric pressure and in the temperature of the air over the land slightly precede changes in the temperature of the surface water. This is quite contrary to the usual idea that the temperature of the water determines that of the land. The detailed curves, however, scarcely leave room for doubt. Finally in widely separated parts of the earth, as Arctowski has well shown (5), and as the Scandinavian authors show more fully, the same variations—even in small details—are repeated synchronously. In other equally scattered areas almost exactly the opposite types of variations occur at the same time. Often an area of one kind lies between areas of the other kind. Thus Helland-Hensen and Nansen conclude that the earth's surface, as Hildebrandsson has already shown (6), is divided into positive and negative centers of action separated by intermediate regions which may be of a transition type, or may be under the sway first of one center and then of another. In these centers, apparently in harmony with solar changes, there occur almost synchronous changes of pressure as well as of temperature. These changes are, apparently, common to all the centers of action, but their character is reversed according as the centers are positive or negative. The changes in pressure appear to precede the changes in temperature. Another noteworthy feature of the centers of action is that one type suffers changes of temperature roughly in harmony with the changes which occur in tropical midcontinental regions and which are apparently due in good part to variations in the radiation of solar heat. The final conclusion of our Norwegian authors is that changes in pressure and winds which are presumably of solar origin, generally precede changes in temperature and are on the whole the more important subject of study.

This conclusion bridges the gap between the present writer's cyclonic hypothesis of variations in temperature and the hypothesis of the present paper as to the effect of nonthermal solar variations. Apparently these solar variations follow a course roughly, but not strictly, parallel with that of changes in the sun's emission of heat. Increased solar heat warms the earth's surface in certain regions, specially within the Tropics or in continental interiors where there are few clouds. This tends to increase the rapidity of both oceanic and atmospheric circulation. At the same time the seemingly nonthermal energy with which we have been mainly dealing in this paper, apparently causes an expansion of areas of high pressure and a consequent weakening of gradients in their centers. This crowds the low-pressure areas and thus in such areas strengthens the gradients. Perhaps, as Veeder has suggested (7), these changes are due to an actual transfer of parts of the upper air toward the centers of high pressure. However this may be, the result seems to be a remarkably quick readjustment of atmospheric pressure. This is apparently followed at once by a strengthening of the winds, and an increase in cyclonic activity. Hence in the high-pressure areas the cold upper air must begin to settle downward, so that the temperature of the earth's surface is lowered. In the low-pressure areas, or at least along their equatorward sides, an unusual amount of warm air must be drawn inward. Thus the temperature rises, and the condition of such places varies inversely to that of the centers of high pressure. Ultimately the warm air is carried upward so that the general temperature of the earth's surface is lowered. This, however, does not happen until certain areas have been warmed by the winds while other areas are being warmed by the sun and still others are being cooled by the descent of air from aloft. One of the next great tasks of meteorologists would seem to be to map the areas of these three types under different conditions of solar activity.

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CORRIGENDA.

PART I.—Page 127, legend for figure 4, the dotted line and the solid line should be interchanged.

Page 129, lower margin of right-hand of figure 5, "increase" should read "decrease."

Page 139, column 2, line 14 from bottom, sentence beginning "Let it" should read "Let us."

II.—Page 170, Table 8, column 1, third line, "1907" should read "1908".

Page 176, second line of note to figure 14, "sun" should read "sun's"; at beginning of fourth line "from" should read "of", and "NS" in same line should read "NE".

LACUSTRAL RECORD OF PAST CLIMATES.

By CHARLES ROLLIN KEYES, Ph. D.

[Dated Des Moines, Iowa, July 14, 1917.]

It is not at all surprising that such apparent climatic anomalies as the occurrence in arid regions of large bodies of inland waters should call forth varied explanations. At first glance interior seas seem to portend former meteorological conditions that were fundamentally different from those now existing. They even suggest that they may be tell-tale clues to epochs when greater humidity prevailed. In this regard the vast extinct lakes of the Great Basin of western North America especially are the theme of warm and prolix discussion on possible climatic changes in late geological times. Whether or not ultimate analysis of recorded observation support the thesis of permanency of climate, rhythmic alternation of climatic change, or variable and irregular succession, it is quite certain that the tendency of opinion toward the middle course thus far finds greatest favor.

When the sumptuous monographs on the vanquished Great Basin lakes were written by King, Whitney, Gilbert, and Russell, such a thing as desert geology was entirely unknown in the United States. Principles of modern physiography were not yet formulated. The tremendous potency of eolic erosion under conditions of aridity was unsuspected. On the other hand, the duality of the Glacial Epoch was just beginning to receive credence, although its real multiplicity and complexity were yet undreamed. Since these new fields of investigation have opened up, old views are capable of something like quantitative measurement, where before much was either pure fancy or unwarranted distortion to fit dimly outlined hypotheses.

Arid regions present as their most characteristic relief expression innumerable shallow depressions. In a tract of close-patterned orogeny as, for example, the Great Basin, these broad depressions are usually coterminous with the intermontane plains. To the explorer fresh from his homeland of humid climate the surface hollows appear as potential lake basins. As a direct consequence of desert erosion they are really not an expression of drainage features at all. That some of them, under such dry-climate conditions, should be actually occupied by broad expanses of water is a wholly unexpected phe-